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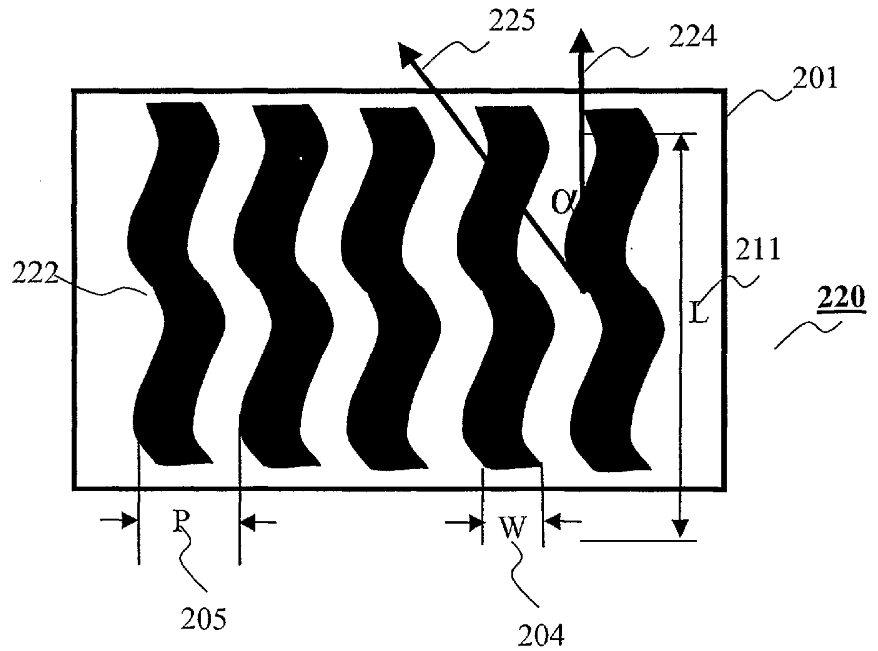
(54) **Title:** LOW FILL FACTOR WIRE GRID POLARIZER



(57) **Abstract:** In an example embodiment, a wire grid polarizer includes a plurality of parallel conductors having a pitch (P), a width (W), and a height (H). In example embodiments, a fill-factor (W/P) is greater than approximately 0.18 and less than approximately 0.25. In another example embodiment, a display system includes a light source and a light-valve. The display system also includes a wire grid polarizer that includes a plurality of parallel conductors having a pitch (P), a width (W), and a height (H). In example embodiments, a fill-factor (W/P) is greater than approximately 0.18 and less than approximately 0.25.

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LOW FILL FACTOR WIRE GRID POLARIZER

FIELD OF THE INVENTION

A polarizer is described for use in enhancing light efficiency.

BACKGROUND OF THE INVENTION

Light-valves are implemented in a wide variety of display technologies. For example, display and microdisplay panels are gaining in popularity in many applications such as televisions, computer monitors, point of sale displays, personal digital assistants and electronic cinema to mention a few applications.

Many light valves are based on liquid crystal (LC) technologies. In some LC technologies light is transmitted through an LC device (panel), while in others the light traverses the panel twice, after being reflected at a far surface of the panel.

In operation, an external field or voltage is used to selectively rotate the axes of the molecules of the LC material. As is well known, by application of this voltage across the LC panel, the direction of the LC molecules can be controlled and the state of polarization of the reflected light is selectively changed. As such, by selective switching of the transistors in the array, the LC medium can be used to modulate the light with image information.

In many LCD systems, light modulation results in dark-state light at certain picture elements (pixels) and bright-state light at others, where the polarization state governs the amount of light transmitted by each pixel element. Thereby, an image is created on a screen by the selective polarization transformation by the LC panel and optics to form the image or 'picture.'

While LCD devices are becoming ubiquitous in display and microdisplay applications, there are certain drawbacks associated with known devices. For example, in known devices some of the light from the light source may be irrecoverably lost and the overall brightness of the image adversely impacted.

This loss of light in display systems may be from a variety of sources within the display system. In many LCD systems, the light from a source is selectively polarized in a particular orientation prior to being incident on the LC panel. This selective polarization may be effected by an absorptive polarizer. The

LC panel may have a voltage selectively applied to orient the molecules of the material in a certain manner. The polarization of the light that is incident on the LC panel is selectively altered upon traversing through the LC layer. Light in one linear polarization state is transmitted by a polarizer (often referred to as an analyzer) as the bright state light; while light of an orthogonal polarization state is absorbed by the analyzer as the dark-state light. As can be appreciated, approximately one-half of the light energy is lost in such a system, due to absorption by the first linear polarizer.

In other display and microdisplay structures, a reflective polarizer may be used for polarization selectivity. Sometimes, the reflective polarizer is placed between a light source and the LC panel in order to provide light (polarization) recycling, wherein one polarization state is desirably transmitted by the reflective polarizer and one polarization state is reflected back toward the light source. In known systems using reflective polarizers, there are competing objectives that impede the polarization recycling. These competing objectives include light transmission efficiency and polarization extinction. For example, wire-grid polarizers may be used as the reflective polarizer. Known wire-grid polarizers have a relatively high extinction ratio. Such known wire-grid polarizers are not desirable in light recycling because the total light throughput is unacceptably low. This can result in unacceptable contrast and brightness in the viewed image.

Alternatively, plastic reflective polarizers comprising multilayer films or immiscible layered materials may be used in displays. Known plastic polarizers have a relatively low extinction ration and relatively high transmission. Such known plastic polarizers are not desirable in light recycling when used with very strong backlights as the plastics can ‘yellow’ due to light absorption. This can result in unacceptable coloration of the viewed image. As such, the need for improved light throughput and stability of coloration has not been met via known devices and structures. What is needed therefore is an apparatus that overcomes at least the drawbacks of known devices described above.

SUMMARY OF THE INVENTION

In accordance with an example embodiment, a wire grid polarizer includes a plurality of parallel conductors having a pitch (P), a width (W), and a height (H). In example embodiments, a fill-factor (W/P) is greater than approximately 0.18 and less than approximately 0.25.

In accordance with another example embodiment, a display system includes a light source and a light-valve. The display system also includes a wire grid polarizer that includes a plurality of parallel conductors having a pitch (P), a width (W), and a height (H). In example embodiments, a fill-factor (W/P) is greater than approximately 0.18 and less than approximately 0.25.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read with the accompanying drawing figures. It is emphasized that the various features are not necessarily drawn to scale. In fact, the dimensions may be arbitrarily increased or decreased for clarity of discussion.

Fig. 1A is a cross-sectional view of a liquid crystal display device in accordance with an example embodiment.

Fig. 1B is a cross-sectional view of a liquid crystal display device in accordance with an example embodiment.

Fig. 2A is a cross-sectional view of a wire grid polarizer in accordance with an example embodiment.

Fig. 2B is a top view of a wire grid polarizer in accordance with an example embodiment.

Fig. 2C is a top view of a wire grid polarizer showing parallel wires which are not straight according to another embodiment.

Fig. 2D is a top view of a wire grid polarizer showing parallel wires of finite length L arranged randomly according to another embodiment of the wire grid polarizer.

Figs. 3A and 3B are graphical representations showing the transmitted intensity of light of a first polarization state and the reflected polarization state of light of a second polarization state versus the duty cycle of wire grid polarizers in accordance with an example embodiment.

Figs. 4A and 4B are graphical representations showing the transmitted intensity versus duty cycle of wire grid polarizers in accordance with an example embodiment.

Fig. 5A is a graphical representation showing the transmittance of polarized light versus wavelength of a wire grid polarizer in accordance with an example embodiment.

Fig. 5B is a graphical representation showing the reflectance of polarized light versus wavelength of a wire grid polarizer in accordance with an example embodiment.

Fig. 6A is a graphical representation showing the transmittance of polarized light versus angle of incidence (from the normal to the plane of the polarizer) of a wire grid polarizer in accordance with an example embodiment.

Fig. 6B is a graphical representation showing the reflectance of polarized light versus angle of incidence (from the normal to the plane of the polarizer) of a wire grid polarizer in accordance with an example embodiment.

Fig. 7A is a graphical representation showing a function of merit of a display system including a quarter-wave retarder and a reflector versus the duty cycle of a wire grid polarizer in accordance with an example embodiment.

Fig. 7B is an exploded view of Fig. 7A.

Fig. 7C is a graphical representation showing the function of merit of a system including a diffusive reflector versus the duty cycle of a wire grid polarizer in accordance with an example embodiment.

Fig. 7D is an exploded view of Fig. 7C.

Fig. 8 is a cross-sectional view of a wire grid polarizer in accordance with an example embodiment.

Fig. 9 is a cross sectional view of a wire-grid polarizer in accordance with an example embodiment.

Fig. 10 is a cross sectional view of a wire-grid polarizer in accordance with an example embodiment.

Fig. 11 is a cross sectional view of a wire-grid polarizer integrated with one or more additional functional layers in accordance with an example embodiment.

Fig. 12 is a cross sectional view of a wire-grid polarizer interior to a liquid crystal panel in accordance with an example embodiment.

Fig. 13 is a cross sectional view of two wire-grid polarizers used in a display application in accordance with an example embodiment.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description, for purposes of explanation and not limitation, example embodiments disclosing specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure, that the present invention may be practiced in other embodiments that depart from the specific details disclosed herein. Moreover, descriptions of well-known apparati and methods may be omitted so as to not obscure the description of the example embodiments. Such methods and apparati are clearly within the contemplation of the inventors in carrying out the example embodiments. Wherever possible, like numerals refer to like features throughout.

Briefly, and as described in detail in conjunction with example embodiments, a wire grid polarizer and a display system including a wire grid polarizer are disclosed. The wire grid polarizer includes a plurality of conductors having a width, a height and a pitch. In an example embodiment, the wire grid polarizer has a duty cycle chosen to substantially optimize the total light throughput, which is a function of the transmittance of light of a first polarization state through and the reflectance of light of a second polarization state from the wire grid polarizer.

In one example embodiment, the ratio of the height to the pitch of the wire grid polarizer is chosen to substantially optimize total light throughput. In this manner, a greater percentage of the light may be reflected and then transmitted through the wire grid polarizer and the absorptive polarizer, and thereby improve the brightness and contrast of an image provided through the display system.

In another example embodiment the reflected light may be depolarized using a diffusive reflector and reflected back to the polarizer. In yet another example embodiment, the reflected light may traverse a quarter wave retarder, be reflected by a reflector, and traverse the quarter wave retarder a second time before being incident on the wire grid polarizer.

Fig. 1A is a cross-sectional view of a light-valve imaging device 100 of an example embodiment. The imaging device 100 includes a transmissive light-valve 101, which is illustratively an LC panel. The imaging device 100 also includes a reflective polarizer 110, and a pair of absorptive polarizers 102 and 103. The polarizer 102 that is closer to the light guide 105 may be referred to as a rear polarizer. The imaging device may also include a one or more light management films including, but not limited to, brightness enhancement films and diffusers (not shown).

In operation, unpolarized light from a light source(s) 104 is provided through a light guide 105, which may have a diffusive reflector 106 disposed over one or more outer surfaces. As is readily appreciated by one of ordinary skill in the art, the light guide 105, the diffusive reflector 106 and the light management film(s) are useful in providing a uniform light distribution to the light valve 101, with an angular distribution of light that is designed to meet the angular field of view required by an end-user. For example, a laptop computer with a brightness enhancement layer has a viewing angle that is typically on the order of approximately ± 20 degrees off-center axis. Further details of backlight assemblies and the components thereof are described in detail in U.S. Patent Application Serial Number 10/857,515 entitled "Diffuse Reflector Films for Enhanced Liquid Crystal Display Efficiency" to X. Mi et al., filed May 28, 2004 and assigned to the present assignee. The disclosure of this application is specifically incorporated herein by reference.

Light 107 from the light guide 105 is incident on the reflective polarizer 110, which transmits light 108 of a first polarization state (perpendicular to the plane of the page) and reflects light 109 of a second polarization state (parallel to the plane of the page). In the present example embodiment, this light is incident on the light guide 105, and via the diffusive reflection layer 106 is converted to unpolarized light and reintroduced with light 107 to the device 100. In this manner, the light 109 may be reintroduced, or recycled, thereby providing an improved optical efficiency and improved optical performance through improved contrast and brightness.

As can be readily appreciated, the greater the amount of light 108 that is transmitted, the greater the optical efficiency. In accordance with example embodiments, an improvement in the transmission of the light 108 is effected by increasing the transmittance of the reflective polarizer 110 and thus reducing the amount of light that is lost. As will become clearer as the present description continues, this is realized via an improved reflective polarizer of example embodiments.

Fig. 1B is a cross-sectional view of a light-valve imaging device 111 of another example embodiment. The device 111 of the present example embodiment includes many of the same features and elements of the example embodiment of Fig. 1A, and provides light recycling through polarization transformation of at least a portion of the light reflected from the reflective polarizer 110. In accordance with an example embodiment, the polarization transformation is carried out using a quarter wave retarder 112 and a reflective layer 113. Light 109 of the second polarization state is converted to light 114 of the first polarization state by the quarter wave retarder 112 and the reflective layer 113. As such, the required polarization conversion needed for light recycling is effected, and the light 114 is incident on the reflective polarizer in the desired polarization state.

In accordance with an example embodiment, the reflective polarizer 110 is a wire grid polarizer that has an improved transmittance and a reduced loss when compared to known reflective polarizers, such as other wire grid polarizers. An illustrative wire grid polarizer 200 is shown in Fig. 2A and Fig. 2B. Fig. 2A is a cross sectional view and Fig. 2B is a top view of the polarizer 200.

The wire grid polarizer 200 of the example embodiment of Fig. 2A and Fig. 2B may be used as the reflective polarizer 110 in order to improve the optical efficiency through light recycling in LCD structures such as those of Figs. 1A and 1B. The polarizer 200 includes a substrate 201 over which a plurality of conductors (e.g. wires) 202 are disposed. Each of the conductors 202 has a height (H) 203, a width (W) 204, a length (L) and a spacing, or pitch (P) 205, as shown. As will become clearer as the present description continues, controlling these parameters is useful in providing the polarizer 200 with an improved transmittance and a reduced loss compared to known device, thereby improving the light efficiency.

Fig. 2C shows a top view of yet another wire grid polarizer 220 where the wires 222 are parallel to each other but not straight. The wires (referred to as conductors as well) maintain a general direction 224 but at any point along the wires the tangent direction 225 is within an angle, α, of less then approximately 10 degrees or less relative to the general direction 224. In fact the angle, α, may be 5 degrees or less. This relatively small deviation of the wires from being substantially 'straight' in the wire grid polarizer can increase tolerance of alignment of the wire grids relative to the rear polarizer transmission axis, and yet this angle, α, will not significantly affect the performance of the wire grid polarizer 220 in terms of transmittance and reflectance.

Fig. 2D shows yet another illustrative embodiment. In this example embodiment, the polarizer 230 has wires 232 that are substantially parallel to each other with average pitch P_{av} and they have an average finite length L_{av} which is greater than approximately 10 times an average width W_{av} of the wires (aspect ratio). Having a collection of relatively shorter wires of the embodiment of Fig. 2D as opposed to the relatively longer wires of Fig. 2B will be beneficial in manufacturing because shorter wires can form as nano-metal wires or nano-tubes with techniques known in the art.

In accordance with an example embodiment, the substrate 201 may be glass, polymer, or crystalline material that is transparent to the light at the chosen wavelength or wavelength range and provides good adhesion to the conductors

202. The conductors 202 are usefully aluminum or other suitable conductors such as copper, gold, and silver. Typically the more conductive the material chosen for the conductor 202 is in the targeted wavelength range, the better the wire grid polarizer's performance. For example, a good choice for the conductive material is aluminum, as it provides for a broadband reflective polarizer substantially covering the full visible spectrum.

Furthermore, the polarizer 200 may be fabricated using known fabrication techniques. These fabrication techniques include lithography and etching and electron beam etching techniques, to name only a few. It is noted that the fabrication technique chosen must afford the feature sizes, pitch and uniformity discussed below.

A variety of well-known techniques can be used to fabricate the reflective polarizer device, and the choice of fabrication techniques is not critical to the invention as long as the appropriate specifications for the surface texture are met. One method involves depositing and patterning a film of aluminum or silver directly onto a textured substrate. A variety of deposition and patterning techniques common to the semiconductor industry could be used to form a well-defined pattern over the textured surface so long as the method provides a sufficient depth of field. Holographic lithography, as described by Garvin in U.S. Pat. No. 4,049,944, or by Ferranti in U.S. Pat. No. 4,514,479 is a method that offers sufficient resolution and depth of field.

The desired surface texture of the underlying substrate 201 may be effected by mechanical abrasion of the substrate, such as grinding or sand-blasting or by chemical abrasion of the substrate, such as the well known use of dilute hydrofluoric acid to etch glass. Alternatively, a deformable material could be deposited on the substrate and then textured by embossing or by radiation assisted casting, as described by Shvartsman in U.S. Pat. No. 5,279,689. In still another method, the textured surface could be embossed or cast onto a continuous plastic film (for example, using the method described by Blenkhorn in U.S. Pat. No.4, 840,757) that may then be laminated to a rigid substrate.

Still another method for fabricating the diffuse reflective polarizer is to deposit and pattern the grid of parallel conductors on a smooth surface comprised of a polymer film over a rigid substrate, and then emboss the surface texture using the method described by Sager in U.S. Pat. No. 5,466,319. Other combinations of fabrication techniques are surely possible within the scope of the example embodiments. It is noted that the U.S. Patents referenced in connection with the illustrative fabrication techniques are hereby incorporated herein by reference.

The wire grid polarizer 200 provides separation of orthogonally polarized states of light incident thereon. For example, light 206 having orthogonal polarization components in first and second polarization states 207 and 208, respectively, is incident at an angle of incidence (θ) (often referred to as the polar angle) with respect to the normal 209 to the plane of the polarizer 200. Illustratively, the first polarization state 207 is S-polarized light, which is perpendicular to the plane of the page; and the second polarization state is P-polarized light, which is parallel to the plane of the page.

Through the function of the polarizer 200, light 210 of the first polarization state (S-polarization) 207 is reflected from the polarizer 200 and light 211 of the second polarization state (P-polarization) 208 is transmitted through the polarizer. It is further noted that in certain example embodiments the viewing angle may be also measured from a normal to the display surface and thus the wire grid polarizer. It is noted that in some consumer applications, the viewing angle is on the order of approximately + 20 degrees to approximately ± 60 degrees. As such, it is useful to optimize the light output within this angular range.

In certain display applications, it is useful to optimize the amount of light that is incident on the light valve (e.g., light valve 101) and thus to the end-user. As referenced previously, this is effected in example embodiments by increasing the amount of light 211 that is transmitted and by minimizing the loss of light energy that occurs during the polarization separation process of the polarizer 200. In certain illustrative embodiments, this may be effected by providing a duty cycle or fill factor that lies within a certain range. Illustratively, this is effected by determining a value of the pitch 205, P, and varying the width 204, W, to realize the desired duty cycle, W/P. This term (W/P) is often referred to as the fill-factor.

As will be appreciated by one of ordinary skill in the art, the width, W, of the conductors 202 directly impacts the reflection and absorption of light energy of the incident light 206. To this end, the greater the width 204, the greater the amount of S-polarized light that is reflected and the greater the amount of light energy that is absorbed by the conductive material of the polarizer 200. However, the greater the width 204, the less the amount of P-polarized light that is transmitted. As such, and as will become clearer as the present description continues, to the extent possible, it is useful to choose a proper figure of merit by varying the ratio of the width to pitch of the conductor elements..

In other example embodiments, a comparatively improved total light throughput is realized by providing a ratio of the height 203, H, to the pitch 205, P, within a certain range. To wit, the greater the height 203, the greater the amount of S-polarized light that is reflected. However, the greater the height 203, the less the amount of P-polarized light that is transmitted. As such, it is also useful, to choose a proper figure of merit by varying the ratio of width to pitch.

By providing a certain fill factor, or by providing a certain ratio of the height 203 to the pitch 205 (H/P), or both, the wire grid polarizer provides an improved total light throughput and a reduced loss of light energy. It is noted that the improved light throughput of the example embodiments is effected with an extinction ratio (e.g., T_p/T_s where T_p and T_s are the transmittance of S-polarized and P-polarized light, respectively) that is significantly less than known wire grid polarizers. To this end, in known wire grid polarizers it is desired to provide an extinction ratio of 100 or 500 or even 1000. Extinction ratios of this magnitude are desired in many applications in order to improve the contrast ratio of the system. In order to achieve these relatively high extinction ratios, it is necessary to provide a wire grid polarizer that has conductors with dimensional widths and heights that can result in unacceptable reflection and absorption. As such, known wire grid polarizers are not efficient in applications where light recycling is desired.

In accordance with an example embodiment the extinction ratio is on the order of approximately 5:1 to approximately 20:1. These relatively low values notwithstanding, the contrast ratios realized using the wire grid polarizer of example embodiments in systems such as those of the example embodiments of Figs. 1A and 1B are well within acceptable performance values. In fact, applicants have found that in systems such as those of Figs. 1A and 1B, extinction ratios of greater than approximately 10:1 provide no appreciable gain relative to the use of reflective polarizers with much higher extinction ratios. To this end, applicants note that in example embodiments the reflective polarizer 110, 200, utilized as a polarization recycling device, and the polarizers 102, 103 of high extinction ratio, determine the display contrast of the light valve imaging devices 100 and 111.

In example embodiments it is useful to substantially optimize the total light throughput that is a combination of the transmitted light T_p 211 of the second polarization state and the reflected light R_s of the first polarization state 210. This combination fosters an improved optical efficiency in systems such as those of the example embodiments of Figs. 1A and 1B. These aspects of the example embodiments are described presently.

In accordance with certain example embodiments, the wire grid polarizer 110, 200 is used as a polarization recycling device, and via a rather straight-forward analysis, the total light throughput, T1, that is transmitted through the wire grid polarizer and in the transmission axis of the rear polarizer 102 is given by:

$$T1 = \frac{0.5T_P}{1-0.5(R_s+R_p)R} \quad \text{Eqn. 1}$$

or $$T1 = \frac{0.5T_P}{1-0.5R_sR} \quad (\text{when } R_p \ll R_s) \quad \text{Eqn. 2}$$

Eqns. 1 and 2 apply to systems of the example embodiments where the recycling is effected using a diffusive reflector such as reflective layer 106. It is noted that R accounts for the reflectivity of the recycling reflective film, or the efficiency associated with each light recycling. In an ideal case, R is equal to 1, which means that there is no light loss in the light recycling. When R is less than 1, there is some light loss in the light recycling path. It is also noted that T1 is also referred to as the figure of merit for such diffusive reflector-based recycling systems.

In systems that incorporate a reflector and a quarter-wave retarder to effect desired light recycling, the figure of merit is given by the total light, T2, which is transmitted through the wire grid polarizer and in the transmission axis of the rear polarizer 102:

$$T2 = 0.5T_P(1 + RR_s) \quad \text{Eqn. 3}$$

Again, R is the efficiency associated with each light recycling.

In keeping with the example embodiments, regardless of the type of recycling used, it is beneficial to optimize the figure of merit for the respective system in order to improve the amount of light (brightness) of the image formed via the displays of the example embodiments.

In general, six parameters (Ts, Tp, Rs, Rp, As, Ap) are required to describe the optical properties of a wire grid polarizer at a given angle of incidence, where Ts, Rs, As are the Transmittance, Reflectance, and Absorbance of the S-polarized light, respectively, and Tp, Rp, Ap are the Transmittance, Reflectance, and Absorbance of the P-polarization, respectively. They satisfy Ts+Rs+As=1 and Tp+Rp+Ap=1. Therefore, there are 4 independent parameters.

Equations 1 through 3 indicate that the two parameters T_p and R_s are particularly important for polarization recycling. Both T_p and R_s can be controlled by the duty cycle (W/P).

In general, a high duty cycle wire grid polarizer produces a high reflectance R_s and a low transmittance T_p, and a low duty cycle wire grid polarizer produces a low reflectance R_s and a high transmittance T_p. As suggested by U.S. Patent No. 6,108,131 to Hansen et al., when the total efficiency is defined as the sum of R_s and T_p, known wire grid polarizers are likely to have a duty cycle (ratio of elements width to pitch) in a range of 0.40 to 0.60. However, as discussed, in connection with the example embodiments the figure of merit for the polarization recycling is given by either equation 1, equation 2, or equation 3 and not by the sum of R_s and T_p. Applicants have discovered that the figure of merit function of the example embodiment actually provides a duty cycle of the wire grid polarizer for polarization recycle that is quite different from the duty cycle of known wire grid polarizers having a duty cycle in the range of 0.40 to 0.60. To wit, and as will become clearer from the following description, the duty cycle of wire grid polarizers of the example embodiments is in the range of approximately 0.18 to approximately 0.25.

In the example embodiments, the improved total light throughput (T1 or T2) due to the improved transmittance T_p, at the expense of the reflectance R_s, is realized by providing a comparatively reduced width 204, or height 203, or both.

In order to further illustrate the example embodiments, the following graphical representations are described. It is noted that these graphical representations are illustrative of the benefits provided by the example embodiments, and are not intended to be limiting.

Fig. 3A is a graph of the intensity versus the duty cycle for a wire grid polarizer of an example embodiment. The wire grid polarizer may be of the type described in connection with Fig.2, for example, and having aluminum conductors 202 disposed over a fused silica substrate 201. The data of the graph of Figs. 3A and 3B are from such a structure having a pitch of 140 nm, a height of 140 nm, normal incident light having a wavelength of 550 nm. By variation of the width, the duty cycle is varied. The curve 301 shows the transmittance of P-polarization state light, while the curve 302 shows the reflectance of S-polarization state light.

As can be readily appreciated, the transmittance T_p decreases with the duty cycle, and the reflectance R_s increases with the duty cycle. When the duty cycle is low, for example approaching approximately 0.0, the transmittance T_p is approximately 97%; however, the reflectance R_s is too low, only about 3%. At the opposite extreme, when the duty cycle is high, for example approaching approximately 1.00, the reflectance R_s is high, close to 92%, but the transmittance T_p is nearly 0%. Under either extreme case, the wire grid polarizer is not efficient in polarization recycling. Thus, a tradeoff must be made between the transmittance T_p and the reflectance R_s to maximize the total light throughput, such as described by equation 1 or equation 3, by varying the ratio of the width to pitch, and the ratio of the height to pitch.

Fig. 3B is a graph of the merit functions versus the duty cycle in accordance with example embodiments. The data depicted in the graph of 3B are from the wire grid polarizer described in connection with the example embodiments of Fig. 3A. Curve 303 shows the merit function (T2) versus duty cycle for the wire grid polarizer disposed in a display system that effects polarization recycling via a quarter wave retarder and a reflecting elements, such as the system of the example embodiment of Fig. 1B. Curve 304 shows the merit function (T1) versus duty cycle for a wire grid polarizer implemented in a display system that provides light recycling using a diffusive reflector, such as the system of the example embodiment of Fig. 1A.

As can be readily appreciated from a review of both curves 303 and 304, the function of merit is substantially optimal at a duty cycle of approximately 0.18 to approximately 0.25, with a peak value at approximately 0.22 for each system. Thus, the total light output of a display including a wire grid polarizer and a light recycling by diffusion reflection of light of one polarization state or by polarization transformation and reflection, is optimal if the wire grid polarizer has a duty cycle of approximately 0.18 to approximately 0.25. This is contrasted with the figures of merit for known devices having duty cycles of range of 0.40 to 0.60. As can be appreciated the figures of merit for these known wire grid polarizers, which are not useful for recycling, are significantly lower than the figures of merit (T1, T2) of the wire grid polarizer of the example embodiments,.

Figs.4A and 4B show graphically T1 and T2 vs. duty cycle with R varying from approximately 0.5 (50%) to approximately 1.0 (100%). The data are computed from a wire grid structure as described in connection with an example embodiment having a pitch of approximately 140.0 nm, a height of approximately140.0 nm, and normally incident light having a wavelength of approximately 550 nm. It can be seen that the greater the value of R, the better are T1 and T2. However, regardless of the value of R, the best values of T1 and T2 occur when the duty cycle is in approximately the range of approximately 0.18 to approximately 0.25. In other words, R does not significantly impact the dependence of T1 and T2 on the duty cycle. For simplicity, R is chosen to be 1 in the following discussion.

In the preceding examples, R has been assumed to be 1 for simplified discussion. In the event that R is smaller than 1, R_s can be rescaled smaller to account for the impact of R. In the examples, T1 and T2 are beneficially improved, which clearly requires the improvement of the combination of the transmittance of the P-polarization (T_p) and the reflectance of the S-polarization (R_s). To this end, and as can be readily appreciated, the greater the transmittance of the P-polarization (T_p) and the greater the reflectance of the S-polarization (R_s), the higher the total throughput is.

The data shown in Figs. 3A, 3B and 4A through 4B, are for normally incident light. In practice light comes from all directions in a given viewing cone. In this case, the total light throughput T1 and T2 are average values over the usable viewing cone. Nonetheless, applicants have discovered that although the absolute values of T1 and T2 may vary, the maximum total light throughput still is achieved with wire grid polarizer of example embodiments having a duty cycle of approximately 0.18 to approximately 0.25.

Figs. 5A and 5B are graphical representations of the transmittance T_p (%) and reflectance R_s, respectively, as a function of incident wavelength for a wire grid polarizer according to example embodiments. In the present example embodiment, the wire grid polarizer has a pitch of approximately 140 nm and a duty cycle of approximately 0.20. The curve 501 shows that the transmittance of the light of the transmitted P-polarization state is substantially maintained across the entire wavelength range. Similarly, the reflectance of the light of the reflected polarization state (s-polarization state) is shown by curve 502 and is substantially independent of the wavelength. Such performance is required in color display applications.

As referenced previously, the angle of incidence to the polarizer may impact the light output of the wire grid polarizer. Fig. 6A and 6B show the transmittance T_p (%) of the light of the transmitted polarization state and the reflectance R_s (%) of the reflected polarization state, respectively, versus the angle of incidence (θ) of wire grid polarizers.

Curve 601 is the transmittance versus θ for a wire grid polarizer having a duty cycle of 0.45, whereas the curve 602 is the transmittance for a wire grid polarizer of an example embodiment having a duty cycle of 0.20.

For an angle of incidence between approximately 0 degrees and 60 degrees, the transmittance is substantially the same for the wire grid polarizer of an example embodiment having a duty cycle of approximately 0.20.

Similarly, and as shown by curve 603 in Fig. 6B over the range of angles of incidence, the wire grid polarizer having a duty cycle of 0.20 in keeping with an illustrative embodiment provided a nearly constant reflectance. This is compared to the reflectance shown by curve 604, which is of a wire grid polarizer having a duty cycle of 0.45.

Figs. 6A and 6B also show the tradeoff between the transmittance T_p and reflectance R_s needed to meet the desired performance in light recycling applications. The wire grid polarizer having a duty cycle of approximately 0.20 has a much higher transmittance T_p (approximately 97% at normal incidence or approximately 0 degree polar angle) than the one with a duty cycle of 0.45 (approximately 85% at normal incidence), though the wire grid polarizer having a duty cycle of 0.2 has a lower reflectance R_s (about 84%) than the one with a duty cycle of 0.45 (about 88% at normal incidence). Overall the total light throughput based upon Eqns. 1, 2 or 3 is higher for the wire grid polarizer with a duty cycle of 0.2 than the one with a duty cycle of 0.45, as discussed referring to Fig. 4.

Figs. 7A and 7C are graphical representations of the merit function versus the duty cycle for a display device incorporating a quarter wave retarder (i.e., T2) and a reflector for recycling and a display device incorporating a diffusive reflector for recycling (i.e., T1), respectively. In the example embodiment, the duty cycle of the wire grid polarizers are in the range of approximately 0.0 to approximately 1.0. In the wire grid polarizers of the example embodiments of Figs. 7A and 7C, the incident light has a wavelength of approximately 550 nm, the pitch is approximately 140 nm, and a number of wire grid polarizers having conductors of a variety of heights are used. To wit, the curves 701 through 712 represent the total light throughput of each of a variety of wire grid polarizers having the same pitch but varying duty cycle and having conductor heights (H) ranging from approximately 80 nm to approximately 200 nm. As such, Figs. 7A and 7C provide data of the effect of conductor height on the total transmittance over a range of duty cycles for each type of recycling system.

As can be readily appreciated from a review of Figs. 7A and 7C, regardless of the height of the conductors, the best total light throughput (figure of merit) for either recycling structure occurs in wire grid polarizers having a duty cycle in the range of 0.18 to approximately 0.25.

Figs. 7B and 7D are exploded views of Figs. 7A and 7C, respectively, for better view of the maximum total light throughput. When the height is in the range of approximately 80 nm to approximately 200 nm, or the ratio of height to pitch is in the range approximately of 0.57 to approximately 1.43, the total light throughput is at a maximum level achieved according to the parameters of the present example embodiment. When the height is greater than approximately 200 nm, or less than approximately 80 nm, the total transmittance is reduced. This is indicated by the total light throughput T1 or T2 at approximately 200 nm as shown by curve 706 in Fig. 7B and curve 712 in Fig. 7D; and approximately 80 nm as shown by curve 701 in Fig. 7B and curve 707 in Fig. 7D, which are lower than T1, or T2 when the height is approximately 100 nm, approximately 120 nm, approximately 140 nm, or approximately 160 nm.

Fig. 8 shows a wire grid polarizer 800 in accordance with an example embodiment. The wire grid polarizer 800 shows the conductors 202 that are substantially rectangular in cross-section, as well as conductors 801 that have imperfections due to manufacturing. As can be appreciated, these imperfections can create variances in the height, width and pitch of the wire grid polarizer 800. Given these imperfections, the fill factor at each height z may be expressed as:

$$f_0(z) \equiv \frac{w_0(z)}{P} \qquad \text{Eqn.3}$$

where $w_0(z)$ is the width of the wires at height z.

The average fill factor over the entire height H is given by:

$$F \equiv \frac{1}{H}\int_0^H f_0(z) = \frac{1}{H}\int_0^H \frac{w_0(z)}{P} = \frac{1}{H \bullet P}\int_0^H w_0(z) = \frac{S}{H \bullet P} \qquad \text{Eqn. 4}$$

where $S \equiv \int_0^H w_0(z)$, which is the area under the surface profile of the wire.

From these expressions, the average width $W_{av} \equiv \frac{S}{H}$, or $W_{av} \equiv F \bullet P$. These are useful in determining the parameters for a wire grid polarizer having an average duty cycle in the range of approximately 0.18 to approximately 0.25.

Finally, it is noted that certain improvement in the light efficiency is realized through the improved light recycling afforded by the wire grid polarizers of the example embodiments. In keeping with the example embodiments, the display devices of the example embodiments of Figs. 1A and 1B realize an overall improvement in the light efficiency of approximately 10%. Moreover, an additional improvement in light efficiency of approximately 4% to approximately 5% can be achieved by incorporating antireflection layer 901. One example embodiment is shown in Fig. 9, where antireflection layers 901, 902 are disposed on either side of the substrate 201 of the wire grid polarizer 900 which further increases the transmittance T_p of the light of P-polarization from 97% to up to 100% with little loss in reflectance R_s. This example embodiment is shown in Fig. 9.

Fig. 10 shows a low fill factor wire grid polarizer structure 1000 according to an example embodiment. In the present example embodiment, the wire grid polarizer is integrated with the rear absorptive polarizer 1001 and shares a common substrate 201.

Fig. 11 shows a further example embodiment 1100 wherein other optical components such as compensation films or retardation films can also be incorporated with the wire grid polarizer. Figure 11 depicts the wire grid elements 202 formed onto a substrate 201. An absorptive polarizer layer 1001 is shown with an additional functional layer 1101. Layer 1101 may comprise a compensation film, for example, although other functional layers could also be envisioned. While Fig. 11 does not indicate the presence of adhesive, barrier, or alignment layers, it can be appreciated that such additional layers would be found in the embodiment of Fig. 11.

In a further example embodiment depicted in Fig. 12, the wire grid polarizer is disposed between the top and bottom substrates of a liquid crystal display panel. In this figure, a similar structure as shown in Fig. 11 is depicted by wire grid assembly 1200, with the wire grid elements 202 located directly on one surface of a substrate 1201 of the liquid crystal cell. The liquid crystal material, electrodes, color filter and other panel elements and layers are not show, but are understood to be located on the same side of substrate 1201 as the wire grid elements

In another example embodiment, shown in Fig. 13, a second wire grid polarizer may be used. The second wire grid polarizer may be substantially the same as one of the wire grid polarizers of the example embodiments. The second wire grid polarizer of assembly 1300 is depicted by substrate 1301 and wire grid elements 1302. This wire grid structure is shown adjacent to the example wire grid assembly of Fig. 12. An air gap 1303 is depicted between the wire grid structure on substrate 1301 and the liquid crystal panel substrate 1003. This air gap is optional, and may be replaced by an adhesive, an index matching layer, or other material selected to produce optimal performance. The added wire grid comprising elements 1302 and substrate 1301 are preferentially located on the backlight side of the liquid crystal panel. Nominally unpolarized light impinges this first reflective polarizer, efficiently transmitting light of a single polarization state. Any residual light of the orthogonal polarization state is reflected by the wire grid polarizer located within the LC panel. It is expected that the joint operation of both wire grid polarizers may provide sufficient polarization extinction to potentially eliminate the need for the absorptive polarizer 1101. Accordingly, the two wire grid polarizers are arranged with their wire elements oriented in a parallel fashion, with the intent to further enhance the polarization extinction of the assembly.

As will be appreciated by one of ordinary skill in the art, by the example embodiments, light that would otherwise be lost may be reintroduced into the display system and thereby improve the brightness and contrast of the image formed. These and other benefits will become readily apparent to one of ordinary skill in the art from a review of the described example embodiments.

In accordance with illustrative embodiments, wire grids polarizers may be used in a display provide an improved optical efficiency (illuminance) compared to known structures that include specular reflectors over certain surfaces of the light guide. Further, the various methods, materials, components and parameters are included by way of example only and not in any limiting sense. Therefore, the embodiments described are illustrative and are useful in providing beneficial backlight assemblies. In view of this disclosure, those skilled in the art can implement the various example devices and methods to effect improved backlight efficiency, while remaining within the scope of the appended claims.

PARTS LIST

100	light-valve imaging device
101	transmissive light-valve
102	absorptive polarizers
103	absorptive polarizers
104	light source
105	light guide
106	diffusive reflector
107	light
108	light
109	light
110	reflective polarizer
111	light-valve imaging device
112	quarter wave retarder
113	reflective layer
114	light
200	wire grid polarizer
201	fused silica substrate
202	plurality of conductors
203	height
204	width
205	pitch
206	light
207	first polarization state
208	second polarization state
209	normal
210	first polarization state
211	transmitted light
220	wire grid polarizer
222	wires
224	general direction

225	tangent direction
230	polarizer
232	wires
301	curve
302	curve
303	curve
304	curve
501	curve
502	curve
601	curve
602	curve
603	curve
604	curve
701	curve
702	curve
703	curve
704	curve
705	curve
706	curve
707	curve
708	curve
709	curve
710	curve
711	curve
712	curve
800	wire grid polarizer
801	conductors
901	antireflection layer
902	antireflection layer
1000	wire grid polarizer structure
1001	rear absorptive polarizer
1003	liquid crystal panel substrate

1100	wire grid polarizer
1101	absorptive polarizer
1200	wire grid assembly
1201	substrate
1300	assembly
1301	substrate
1302	wire grid elements
1303	air gap
H	height
P	pitch
P_{av}	average pitch
L_{av}	average finite length
W	width
W_{av}	average width
(W/P)	fill factor
T1	merit function
T2	merit function
T_s	transmittance (s-polarized light)
T_p	transmittance (p-polarized light)
R_s	reflectance (s-polarized light)
F	average fill factor over H
S	area under surface profile
α	angle
(θ)	angle of incidence

CLAIMS:

1. A wire grid polarizer, comprising:

A plurality of parallel conductors having a pitch (P), a width (W), a height (H), and a length (L); a fill-factor (W/P) is in the range of approximately 0.18 to approximately 0.25; and an aspect ratio (L/P) that is larger than approximately 10.

2. A wire grid polarizer as recited in claim 1, wherein the ratio of the height to the pitch is in the range of approximately 0.57 to approximately 1.43.

3. A wire grid polarizer as recited in claim 1, wherein the wire grid polarizer has an extinction ratio in the range of approximately 5:1 to approximately 20:1.

4. A wire grid polarizer as recited in claim 1 wherein the height is in the range of approximately 80 nm to approximately 200 nm and light incident on the wire grid polarizer has a transmittance that is substantially the same over the range of wavelength of 400 nm to 700 nm.

5. A wire grid polarizer as recited in claim 1, wherein the transmittance of light incident on the wire grid polarizer is substantially the same over a range of angle of incidence of approximately 0.0 degrees to approximately 60.0 degrees.

6. A wire grid polarizer as recited in claim 1, wherein the width is an average width given by $W \equiv \frac{S}{H}$, where $S \equiv \int_0^H w_0(z)$ and $w_0(z)$ is a width of the conductors as a function of height z.

7. A wire grid polarizer as recited in claim 1, further comprising a substrate over which the plurality of conductors is disposed.

8. A wire grid polarizer as recited in claim 1, wherein directions of respective tangents to the plurality of parallel conductors are at finite angles to a general direction of the parallel conductors and wherein the finite angles are less than approximately 10 degrees.

9. A wire grid polarizer as recited in claim 1, wherein the conductors have an average length L_{av} and an average pitch P_{av}; and are arranged in a substantially random fashion parallel to each other and have an average aspect ratio of L_{av}/P_{av} is greater than approximately 10.

10. A wire grid polarizer as recited in claim 7, further comprising a rear polarizer disposed beneath the substrate.

11. A wire grid polarizer as recited in claim 10, wherein the rear polarizer is an absorptive polarizer.

12. A wire grid polarizer as recited in claim 11, wherein the wire grid polarizer is disposed in a liquid crystal (LC) cell structure.

13. A wire grid polarizer as recited in claim 6, wherein the ratio of the height to the pitch is in the range of approximately 0.57 to approximately 1.43.

14. A wire grid polarizer as recited in claim 6, wherein the wire grid polarizer has an extinction ratio in the range of approximately 5:1 to approximately 20:1.

15. A wire grid polarizer as recited in claim 6, wherein the height is in the range of approximately 80 nm to approximately 200 nm and light incident on the wire grid polarizer has a transmittance that is substantially the same over the range of wavelength of 400 nm to 700 nm.

16. A wire grid polarizer as recited in claim 6, wherein the transmittance of light incident on the wire grid polarizer is substantially the same over a range of angle of incidence of approximately 0.0 degrees to approximately 60.0 degrees.

17. A wire grid polarizer as recited in claim 6, further comprising a substrate over which the plurality of conductors is disposed.

18. A wire grid polarizer as recited in claim 17, further comprising a rear polarizer disposed beneath the substrate.

19. A wire grid polarizer as recited in claim 18, wherein the rear polarizer is an absorptive polarizer.

20. A wire grid polarizer as recited in claim 19, wherein the wire grid polarizer is disposed in a liquid crystal (LC) cell structure.

21. A display device, comprising:

a light source;

a light valve; and

a wire grid polarizer, which includes a plurality of parallel conductors having a pitch (P), a width (W), a length (L), a height (H), a fill-factor (W/P) in the range of approximately 0.18 to approximately 0.25, and an aspect ratio (L/P) larger than 10

22. A display device as recited in claim 21, wherein the ratio of the height to the pitch is in the range of approximately 0.57 to approximately 1.43.

23. A display device as recited in claim 21, wherein the wire grid polarizer has an extinction ratio in the range of approximately 5:1 to approximately 20:1.

24. A display device as recited in claim 21, wherein the height is in the range of approximately 80 nm to approximately 200 nm and light incident on the wire grid polarizer has a transmittance that is substantially the same over the range of wavelength of approximately 400 nm to approximately 700 nm.

25. A display device as recited in claim 21, wherein the transmittance of light incident on the wire grid polarizer is substantially the same over a range of angle of incidence of approximately 0.0 degrees to approximately 60.0 degrees.

26. A display device as recited in claim 21 wherein directions of respective tangents to the plurality of parallel conductors are at finite angles to a general direction of the parallel conductors and wherein the finite angles are less than approximately 10 degrees.

27. A display device as recited in claim 21 wherein the conductors have an average length, L_{av}, and an average pitch P_{av}; and are arranged in a substantially random fashion parallel to each other and have an average aspect ratio, L_{av}/P_{av}, is greater than approximately 10.

28. A display device as recited in claim 21, wherein the width is an average width given by $W \equiv \frac{S}{H}$, where $S \equiv \int_0^H w_0(z)$ and $w_0(z)$ is a width of the conductors as a function of height z.

29. A display device as recited in claim 21, wherein the display device further comprises a diffusive reflector.

30. A display device as recited in claim 21, wherein the display device further comprises a quarter wave retarder and a reflector.

31 A display device as recited in claim 29, wherein the total

transmittance is given by $T1 = \frac{0.5T_P}{1-0.5R_s}$ where T_p is the transmittance of the P-polarized light and R_s is the reflectance of S-polarized light that are transmitted through and reflected from the wire grid polarizer, respectively.

32. A display device as recited in claim 30, wherein the total transmittance is given by $T2 = 0.5T_P(1+R_s)$ where T_p is the transmittance of the P-polarized light and R_s is the reflectance of S-polarized light that are transmitted through and reflected from the wire grid polarizer, respectively.

33. A display device as recited in claim 21, further comprising a substrate over which the plurality of conductors is disposed.

34. A display device as recited in claim 33, further comprising a rear polarizer disposed beneath the substrate.

35. A display device as recited in claim 34, wherein the rear polarizer is an absorptive polarizer.

36. A display device as recited in claim 35, wherein the wire grid polarizer is disposed in a liquid crystal (LC) cell structure.

37. A display device as recited in claim 28, wherein the ratio of the height to the pitch is in the range of approximately 0.57 to approximately 1.43.

38. A display device as recited in claim 28, wherein the wire grid polarizer has an extinction ratio in the range of approximately 5:1 to approximately 20:1.

39. A display device as recited in claim 28, wherein the height is in the range of approximately 80 nm to approximately 200 nm and light incident

on the wire grid polarizer has a transmittance that is substantially the same over the rangeof wavelength of 400 nm to 700 nm.

40. A display device as recited in claim 28, wherein the transmittance of light incident on the wire grid polarizer is substantially the same over a range of angle of incidence of approximately 0.0 degrees to approximately 60.0 degrees.

41. A display device as recited in claim 28, further comprising a substrate over which the plurality of conductors is disposed.

42. A display device as recited in claim 41, further comprising a rear polarizer disposed beneath the substrate.

43. A display device as recited in claim 42, wherein the rear polarizer is an absorptive polarizer.

44. A display device as recited in claim 43, wherein the wire grid polarizer is disposed in a liquid crystal (LC) cell structure.

45. A display device as recited in claim 21, further comprising another wire grid polarizer.

46. A display device as recited in claim 21, wherein the wire grid polarizer is disposed between the light source and the light valve.

47. A wire grid polarizer as recited in claim 1, wherein the wire grid polarizer comprises one or more of aluminum, gold, and silver.

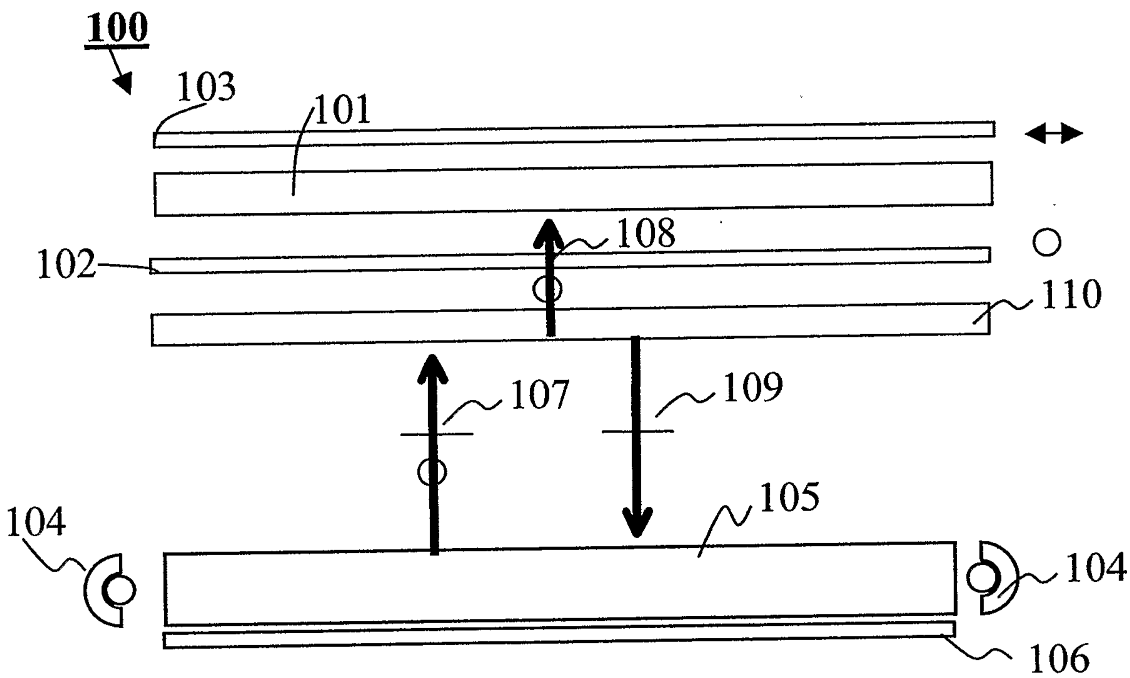


FIG. 1A

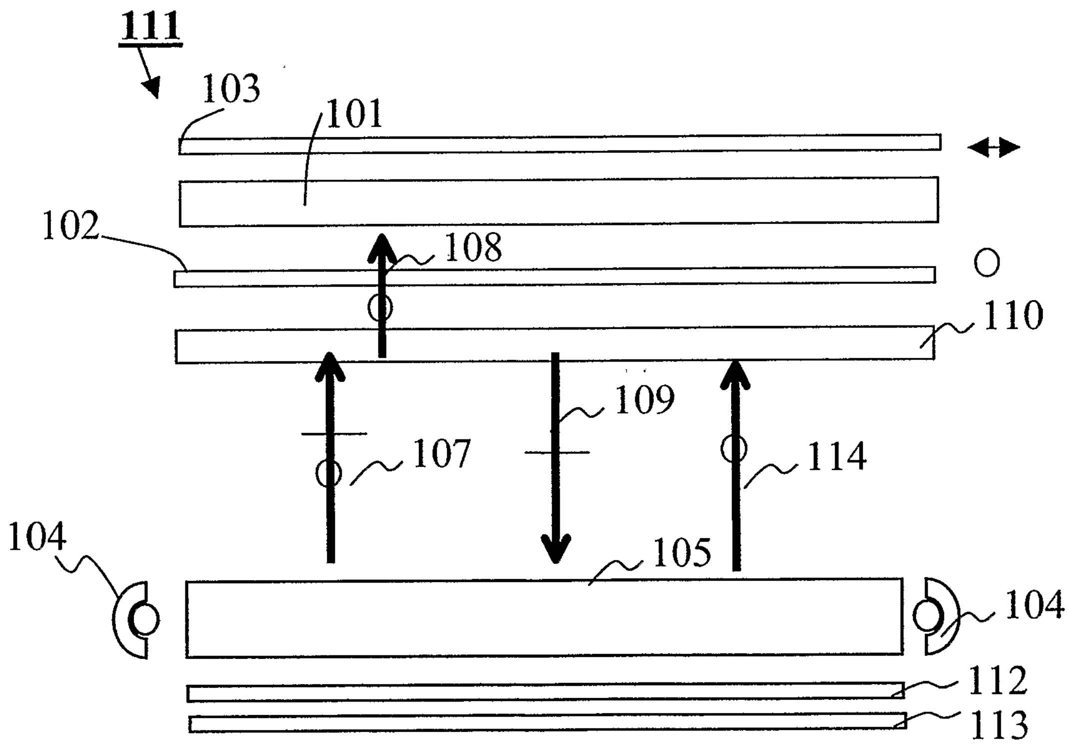


FIG. 1B

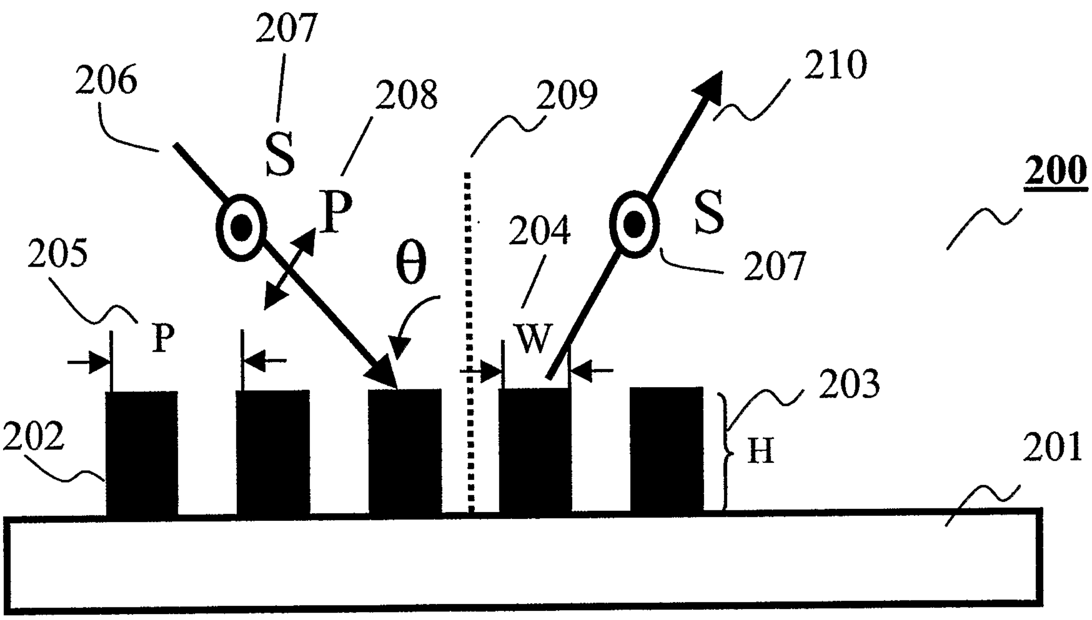


FIG. 2A

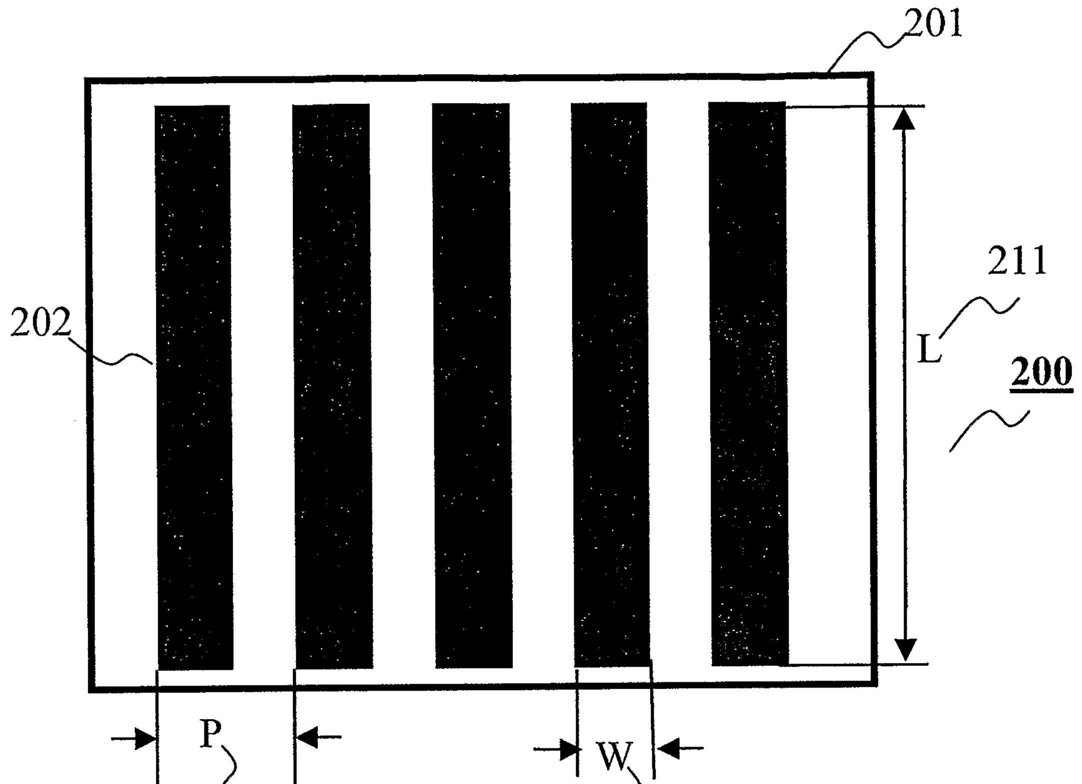


FIG. 2B

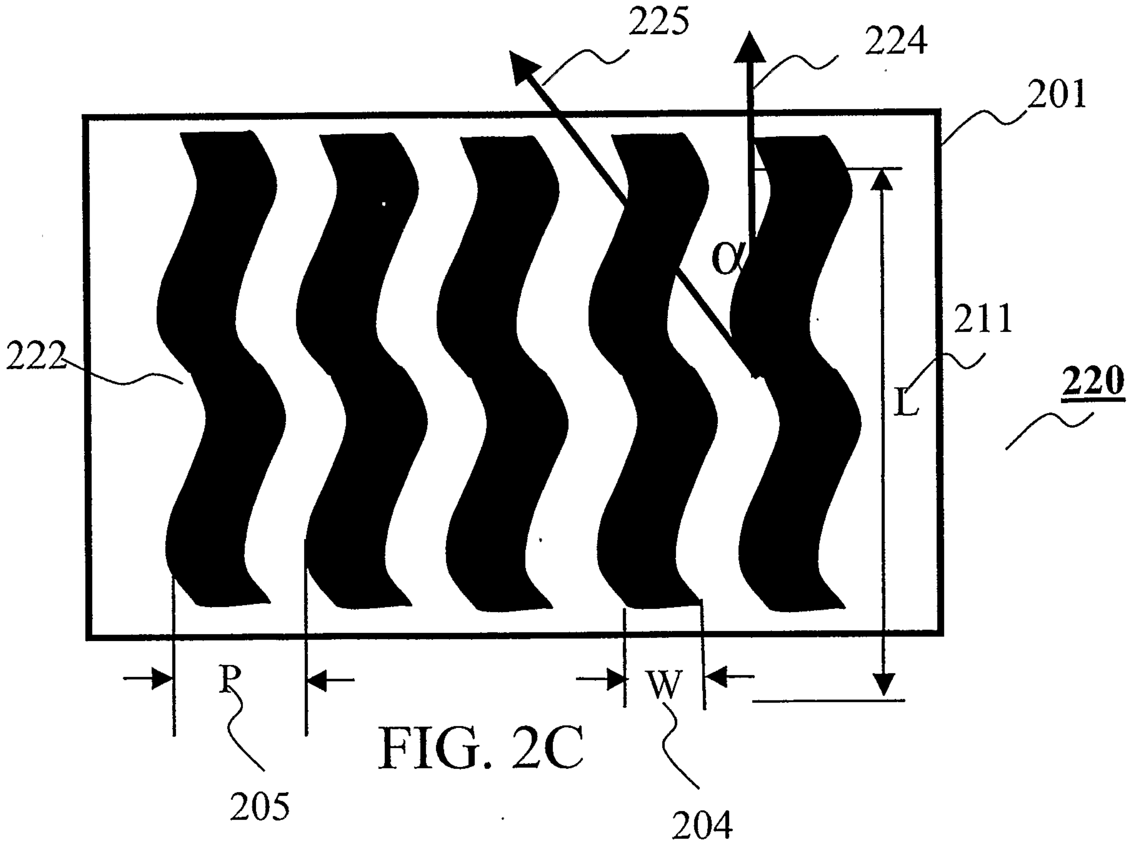


FIG. 2C

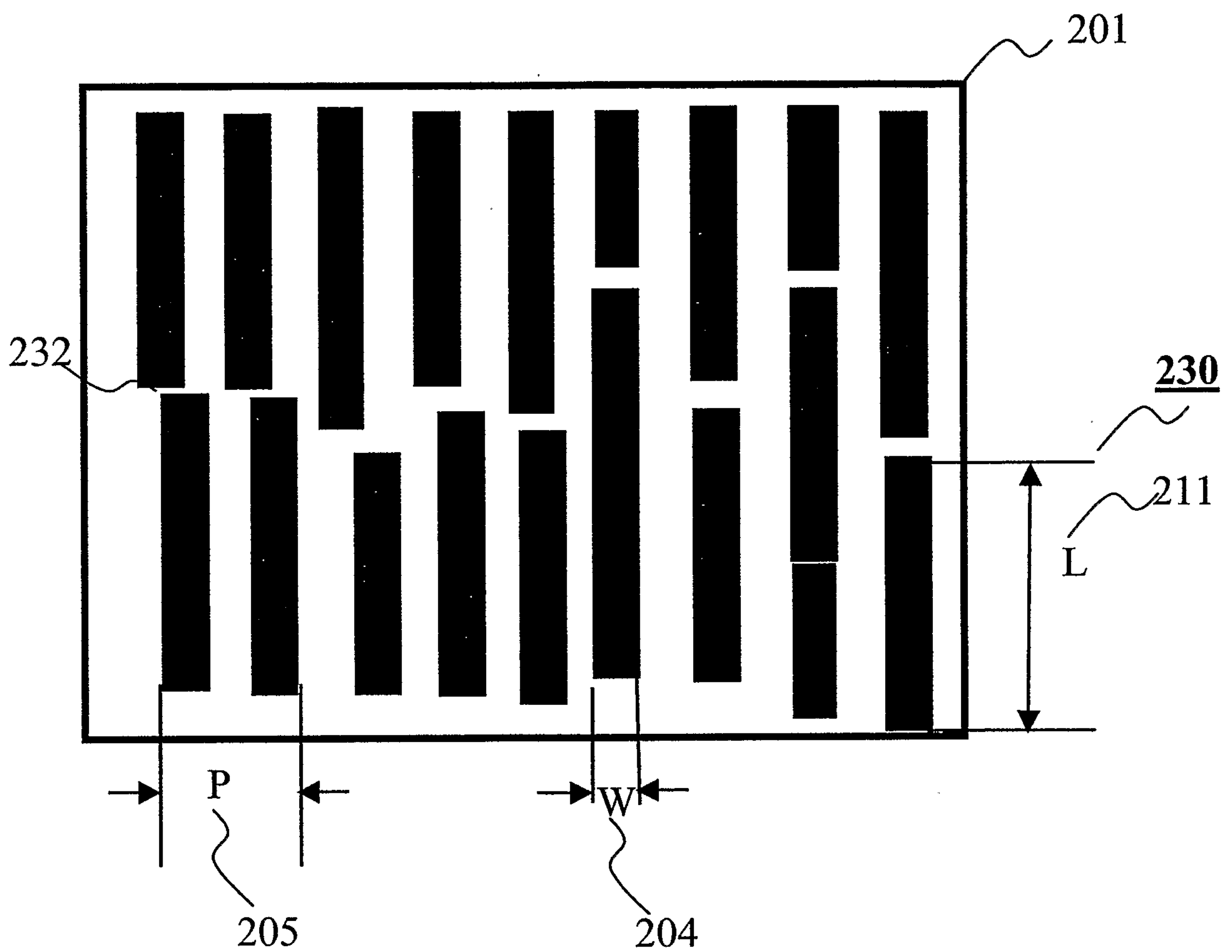


FIG. 2D

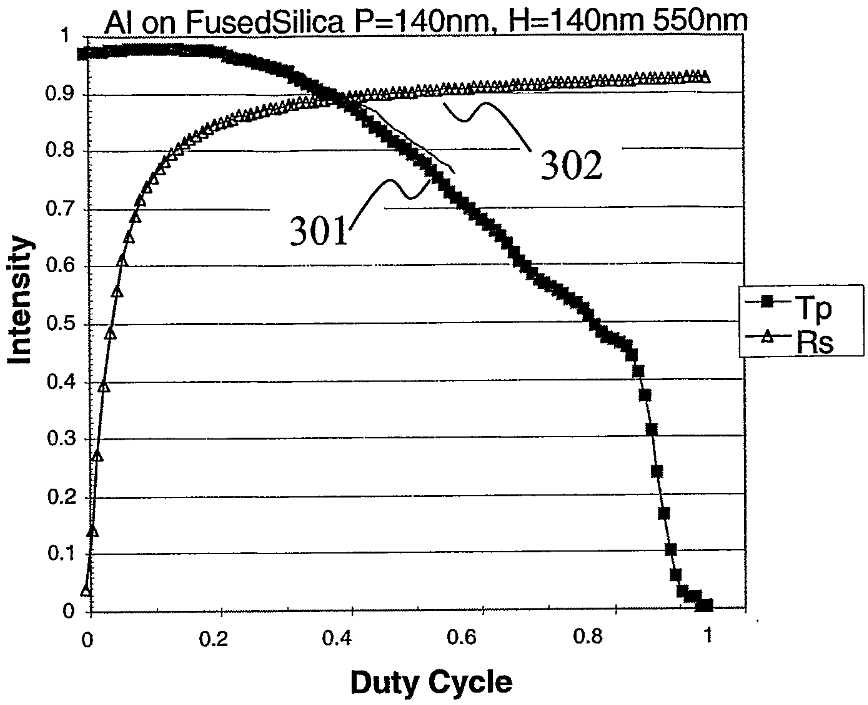

Al on FusedSilica P=140nm, H=140nm 550nm
Intensity
Duty Cycle
Tp
Rs
301
302
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 3A

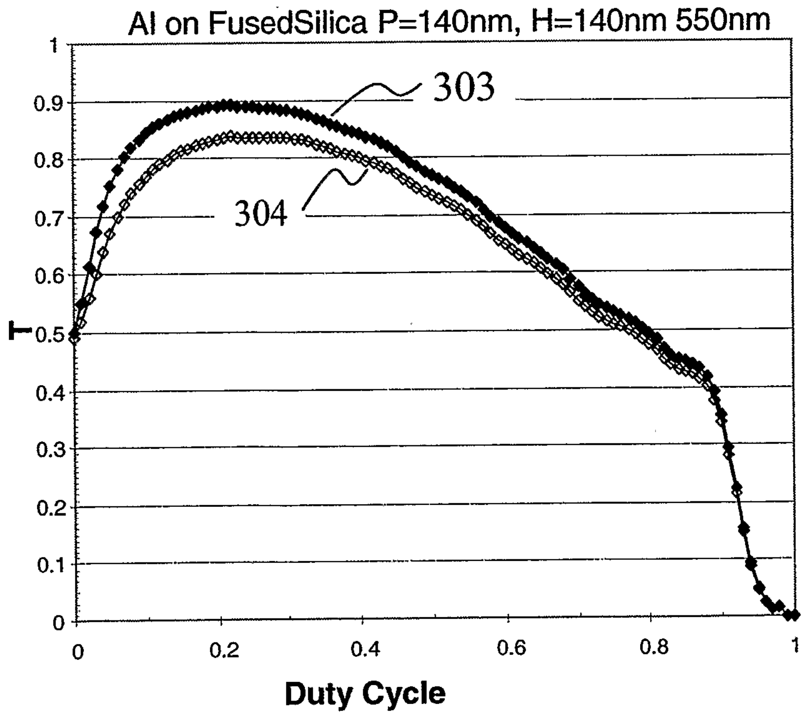
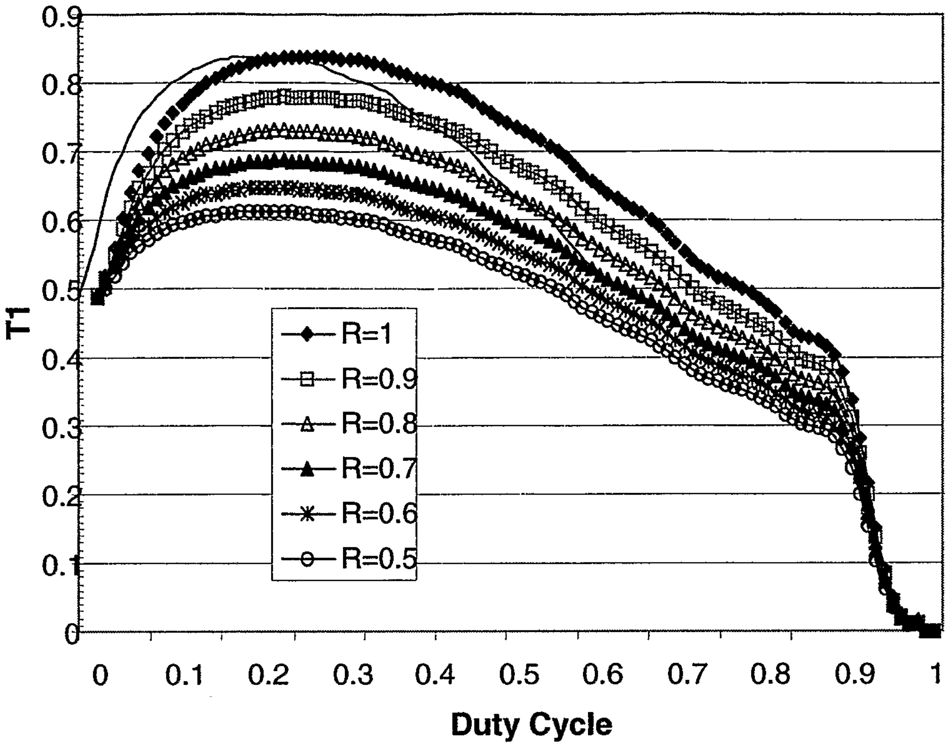
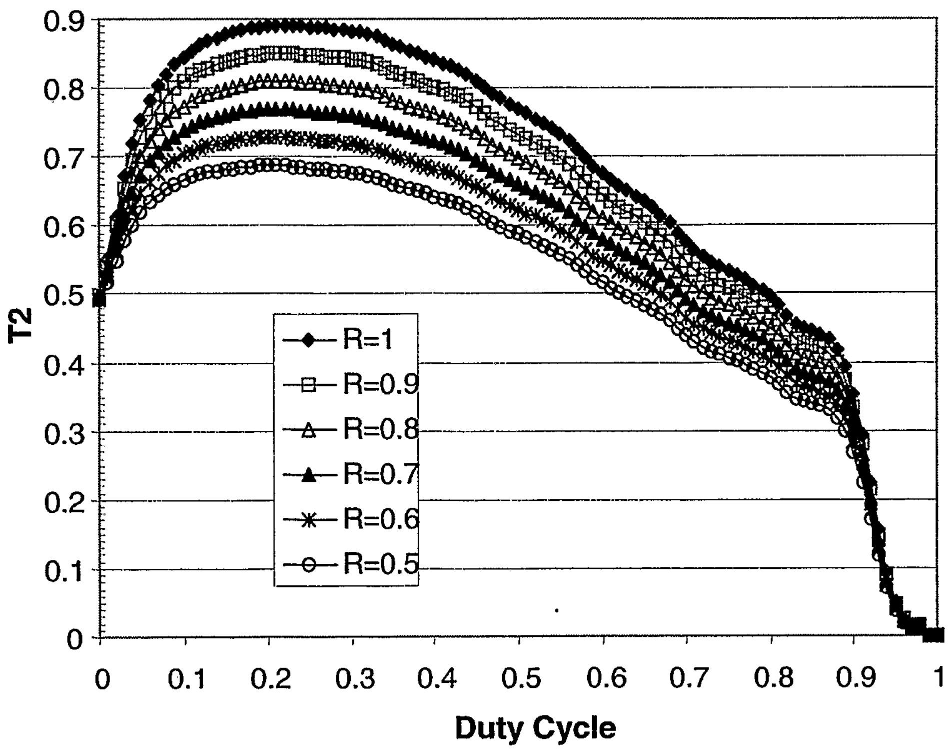

Al on FusedSilica P=140nm, H=140nm 550nm
T
Duty Cycle
303
304
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 3B



T1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
R=1
R=0.9
R=0.8
R=0.7
R=0.6
R=0.5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Duty Cycle

FIG. 4A



T2
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
R=1
R=0.9
R=0.8
R=0.7
R=0.6
R=0.5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Duty Cycle

FIG. 4B

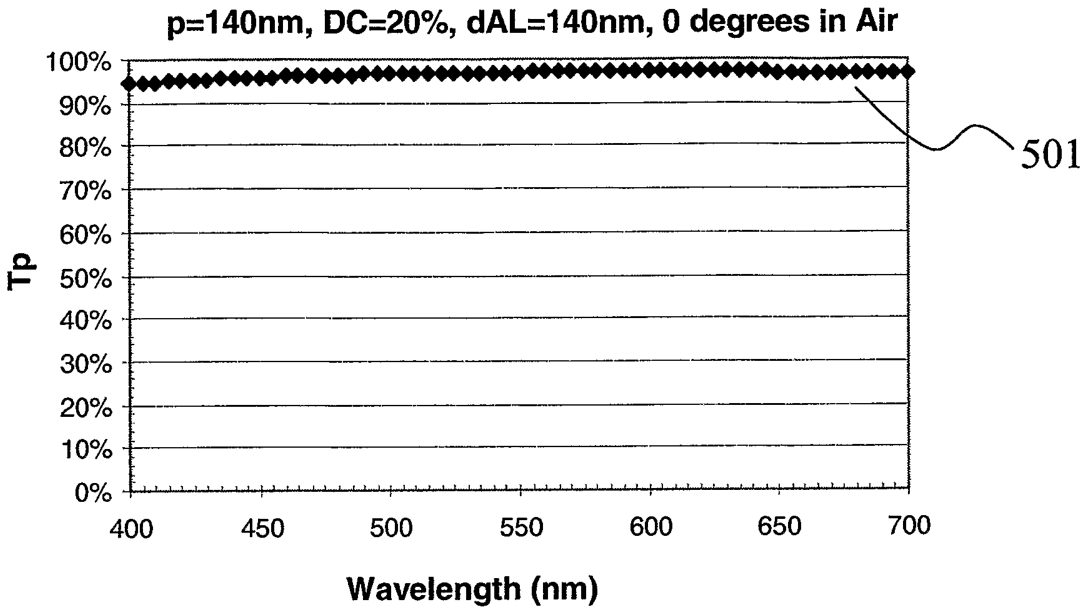

p=140nm, DC=20%, dAL=140nm, 0 degrees in Air
Tp
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
400
450
500
550
600
650
700
Wavelength (nm)
501

FIG. 5A

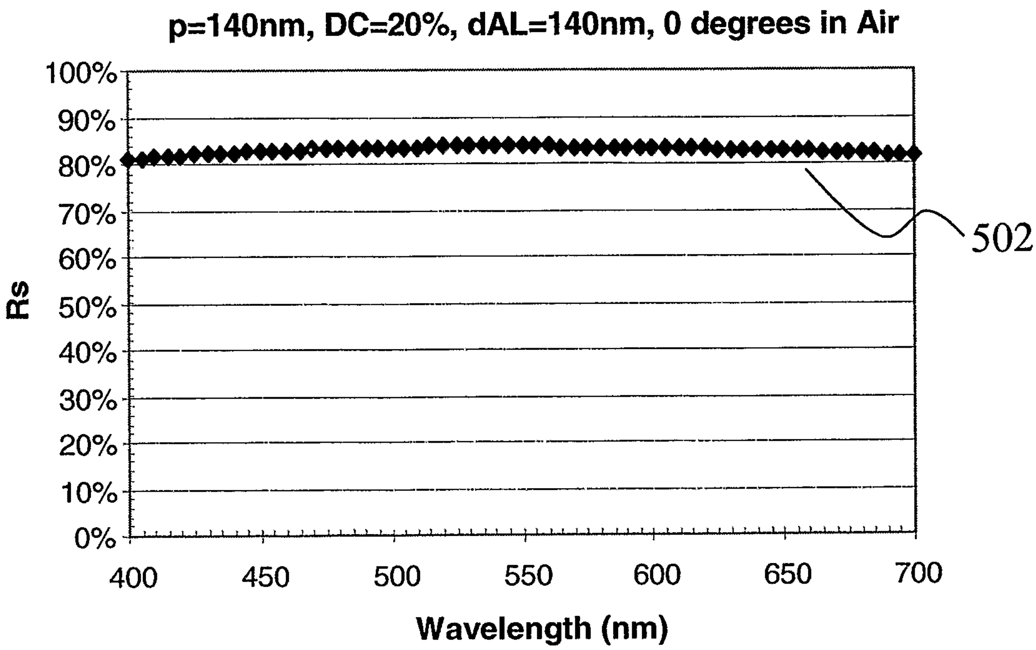

p=140nm, DC=20%, dAL=140nm, 0 degrees in Air
Rs
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
400
450
500
550
600
650
700
Wavelength (nm)
502

FIG. 5B

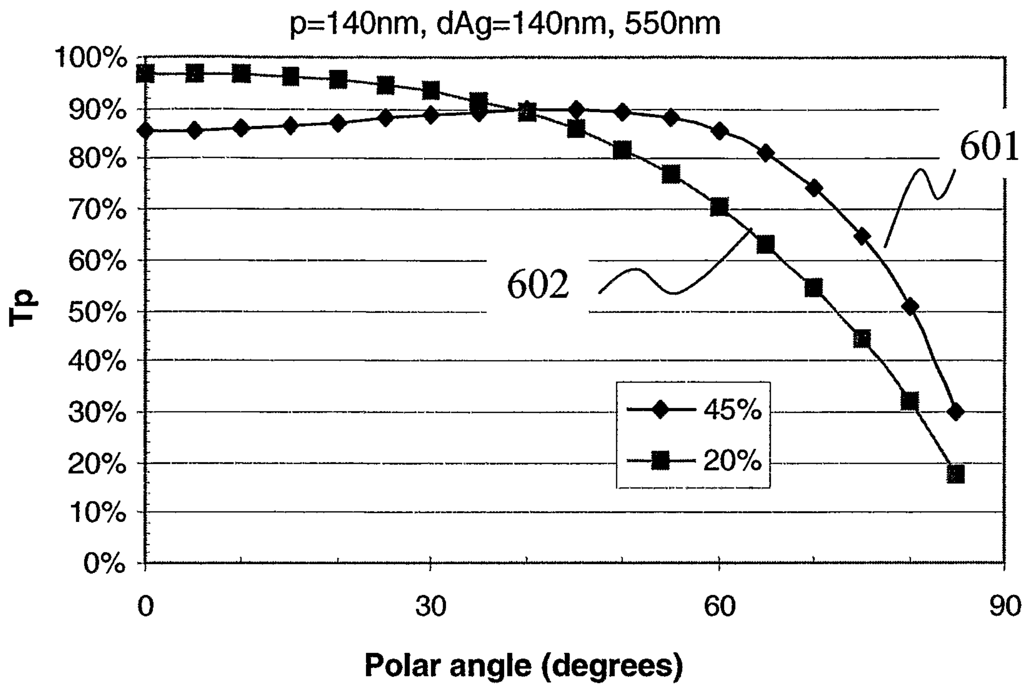

p=140nm, dAg=140nm, 550nm
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Tp
0
30
60
90
Polar angle (degrees)
601
602
45%
20%

FIG. 6A

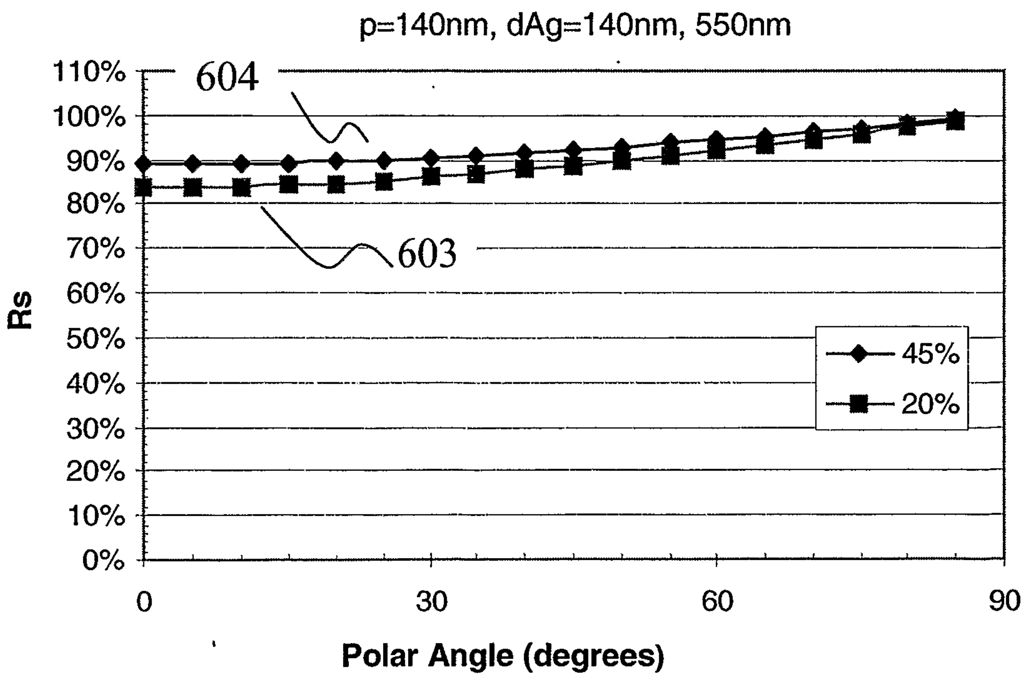

p=140nm, dAg=140nm, 550nm
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Rs
0
30
60
90
Polar Angle (degrees)
604
603
45%
20%

FIG. 6B

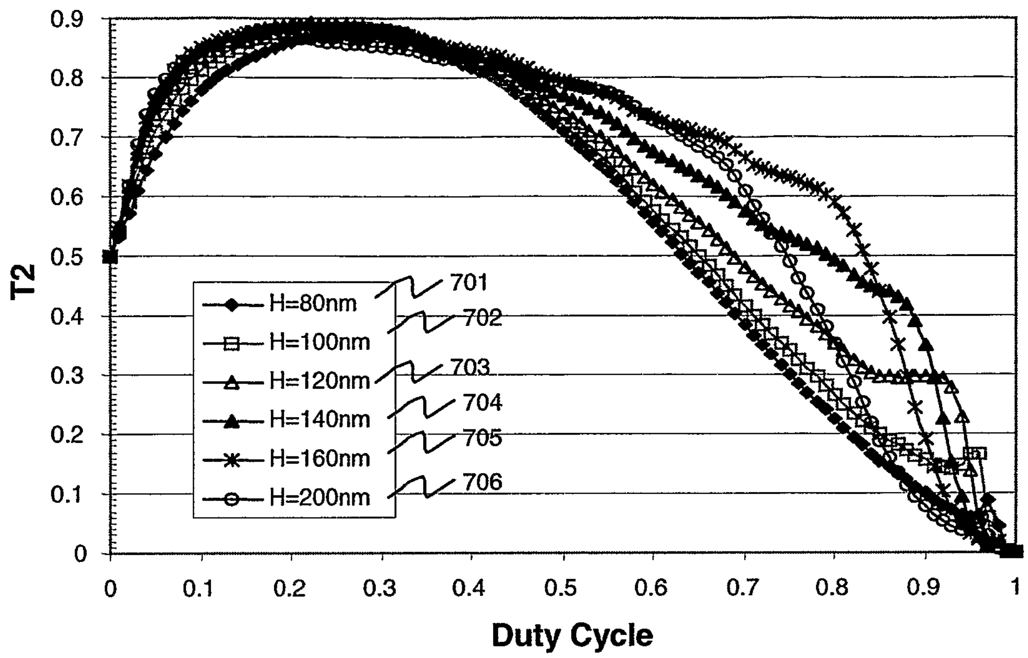

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
T2
H=80nm
H=100nm
H=120nm
H=140nm
H=160nm
H=200nm
701
702
703
704
705
706
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Duty Cycle

FIG. 7A

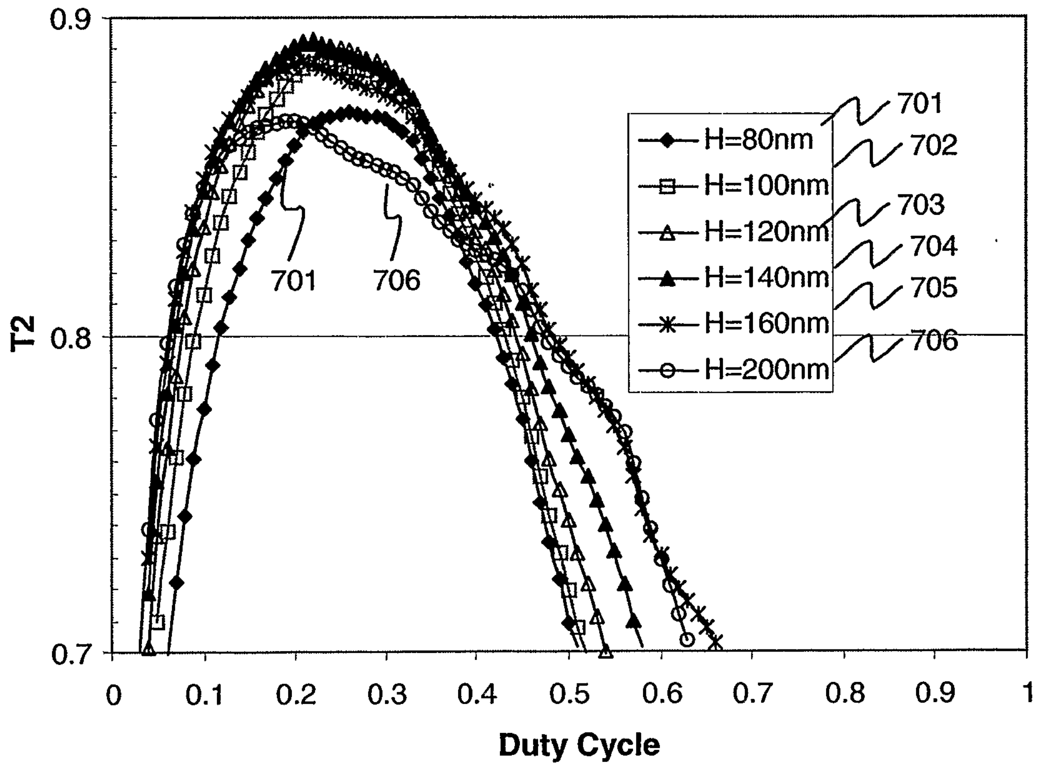

0.9
0.8
0.7
T2
701
706
H=80nm
H=100nm
H=120nm
H=140nm
H=160nm
H=200nm
701
702
703
704
705
706
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Duty Cycle

FIG. 7B

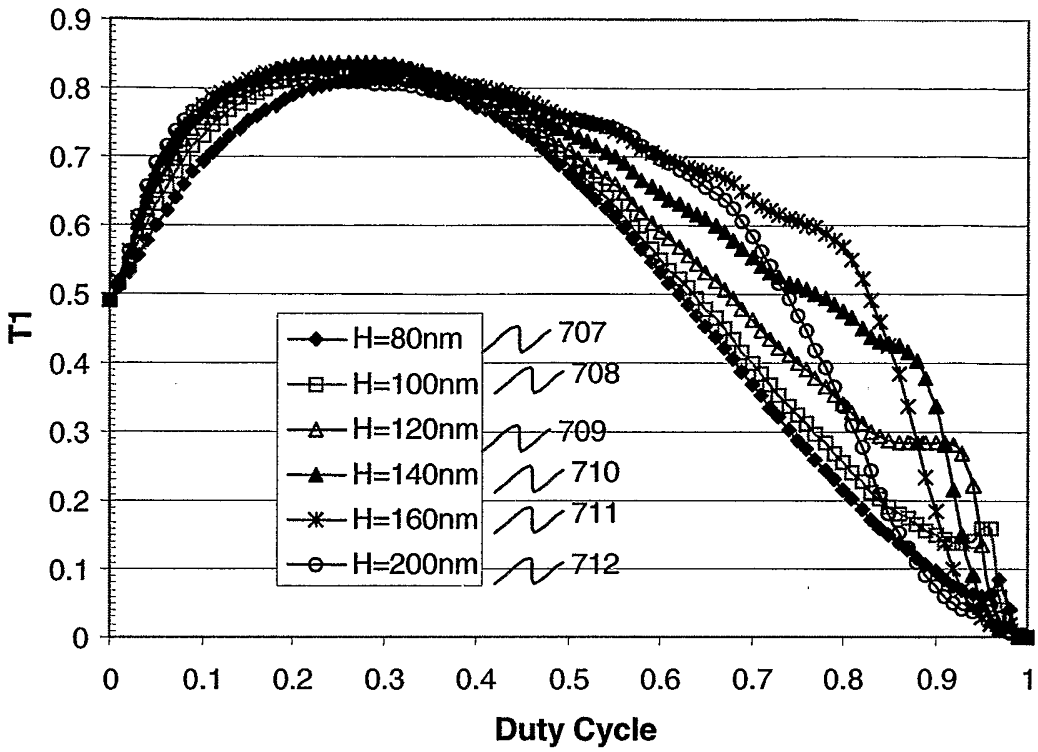

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
T1
H=80nm
H=100nm
H=120nm
H=140nm
H=160nm
H=200nm
707
708
709
710
711
712
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Duty Cycle

FIG. 7C

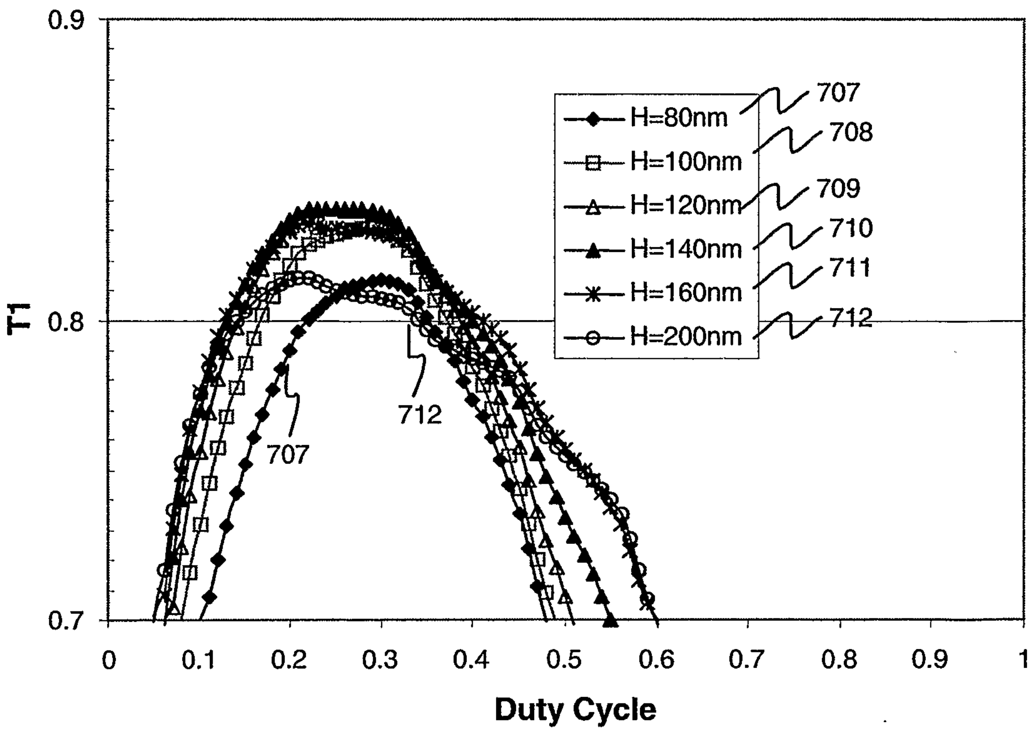

0.9
0.8
0.7
T1
H=80nm
H=100nm
H=120nm
H=140nm
H=160nm
H=200nm
707
708
709
710
711
712
707
712
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Duty Cycle

FIG. 7D

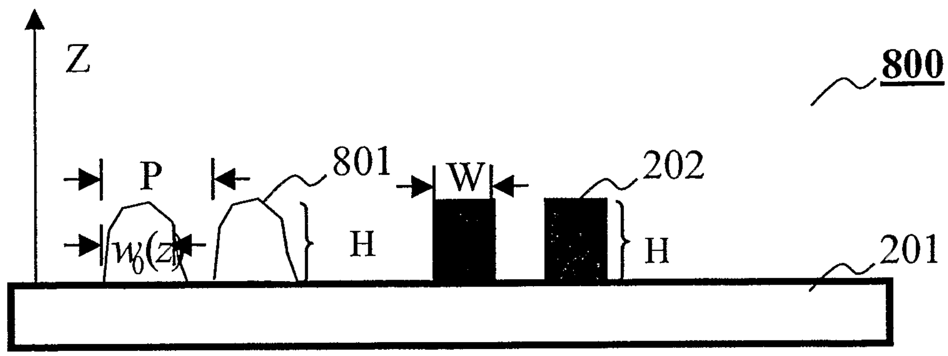


FIG. 8

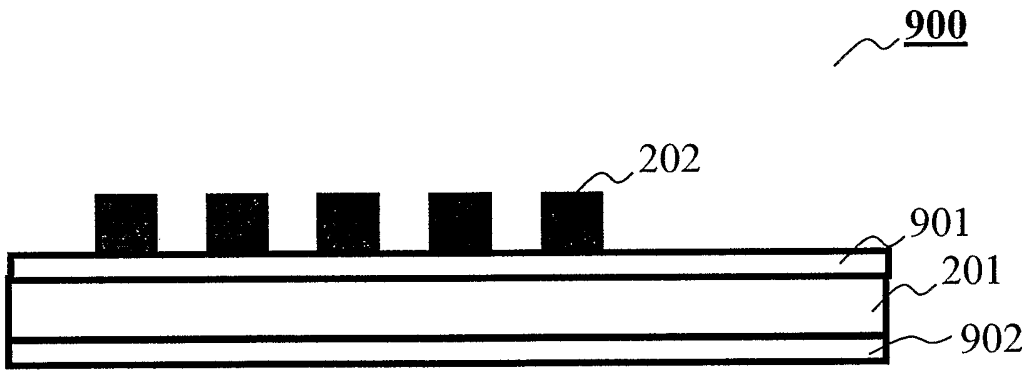


FIG. 9

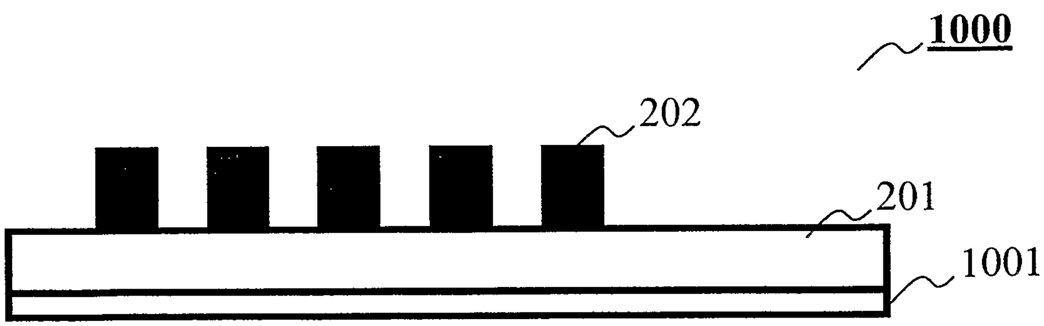


FIG. 10

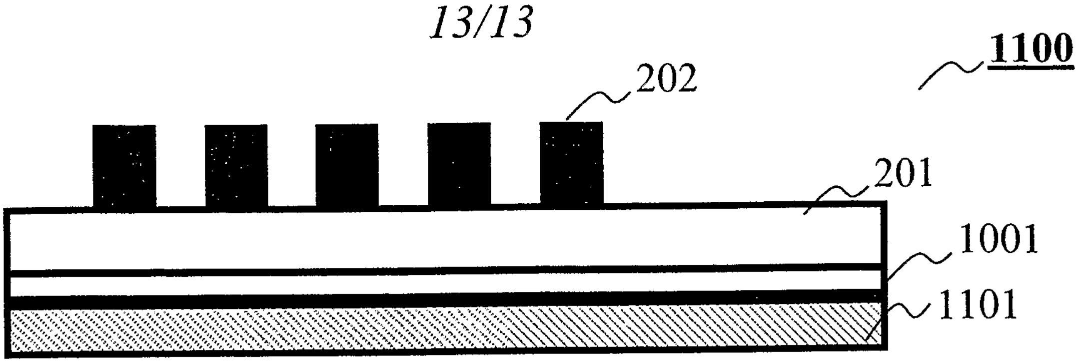


FIG. 11

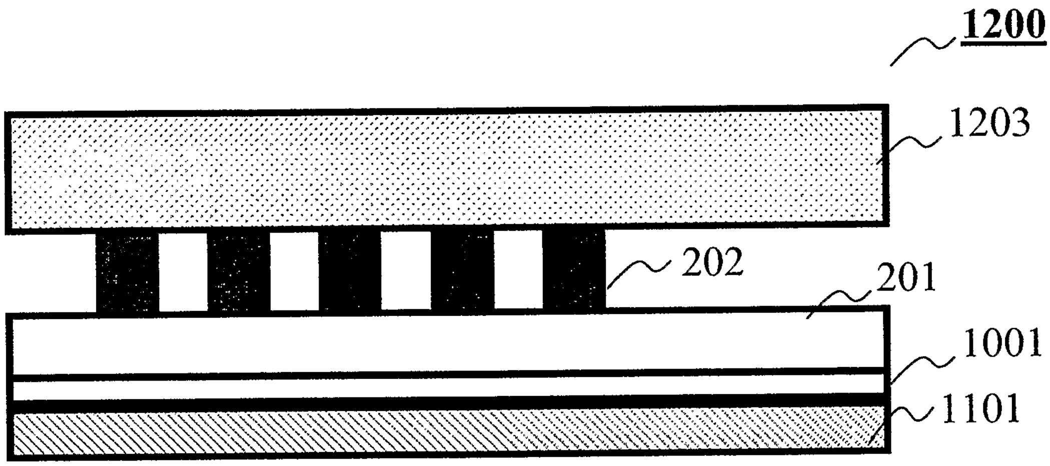


FIG. 12

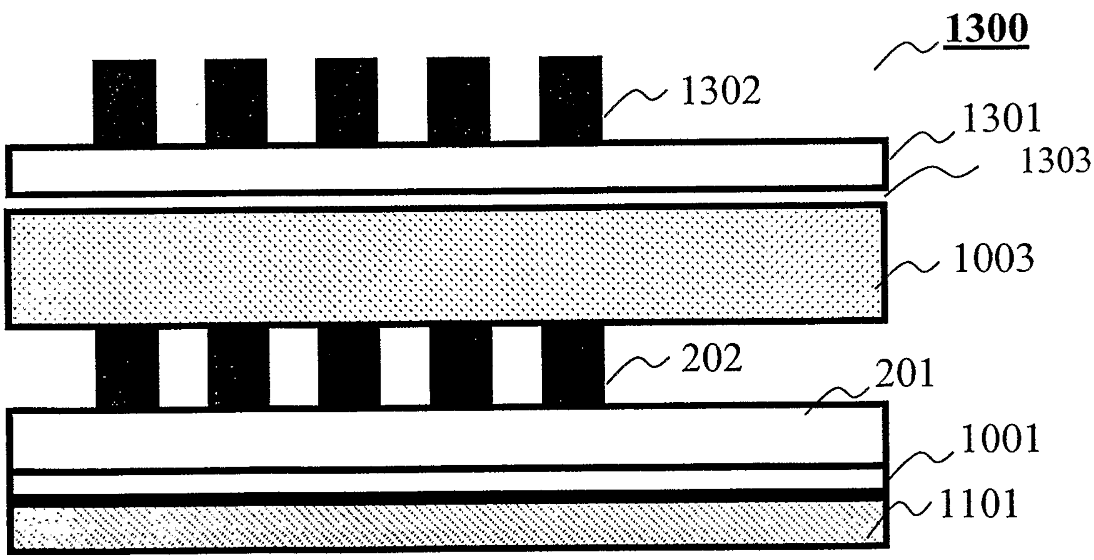


FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/032656

A. CLASSIFICATION OF SUBJECT MATTER
G02B5/30 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2004/174596 A1 (UMEKI KAZUHIRO) 9 September 2004 (2004-09-09) paragraphs ‘0088!, ‘0089!, ‘0094! figures 1,2a,2b -----	1-8, 13-17,47 10-12, 18-26, 28-44,46
Y	EP 1 180 711 A (SEIKO EPSON CORPORATION) 20 February 2002 (2002-02-20) paragraph ‘0028! - paragraph ‘0030! paragraphs ‘0071!, ‘0090! paragraph ‘0084! - paragraph ‘0086! figures 1,2a,3-5 ----- -/--	10-12, 18-46

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
20 December 2005	05/01/2006

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	von Hentig, R

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/032656

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	page 4741 - 4745, 3. Results page 4745, 4. Summary figures 2-4,10	10-12, 18-26, 28-44,46
X	JENSEN M A ET AL: "Finite-aperture wire grid polarizers" JOURNAL OF THE OPTICAL SOCIETY OF AMERICA A (OPTICS, IMAGE SCIENCE AND VISION) OPT. SOC. AMERICA USA, vol. 17, no. 12, December 2000 (2000-12), pages 2191-2198, XP002360133 ISSN: 0740-3232	1-8, 13-17
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Y	page 964, left-hand column - page 965, right-hand column figure 1	27-44,46
X	WO 2004/019070 A (NANOOPTO CORPORATION) 4 March 2004 (2004-03-04)	1-10, 13-18
Y	paragraph '0028! - paragraph '0036! figure 2	21-26, 28-46

INTERNATIONAL SEARCH REPORT

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Inter nal Application No
PCT/US2005/032656

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